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Active Control of Stall and Surge

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Contents

1) Introduction

The detrimental effects of rotating stall and surge on compressor performance were discussed in the previous lecture. The onset of these disturbances is therefore to be avoided at all costs and this is usually done by using a safety margin which restricts compressor operation to points well removed from the stability boundary. The stability boundary itself is ill-defined and therefore the safety margin needs to be quite generous. In most compressor designs peak efficiency occurs in close proximity to peak pressure rise and therefore a large safety margin is particularly wasteful of useful operating range.

In the past, many attempts have been made to cut down on the size of the safety margin by introducing detection and correction equipment. This involves the use of a control system which senses the approach of stall or surge and then initiates remedial action fast enough to prevent disturbances from growing to detrimental proportions. Ludwig and Nenni (Ref.1) suggested the use of fast blow-off valves, while Reiss et al (Ref.2) proposed a successful system using rapid rescheduling of stator vanes. Control of stall and surge by these methods is termed avoidance control.

In recent years an alternative approach to stall and surge control has been proposed based on the growing science of active control. The first published work on this topic is the landmark paper of Epstein, Ffowcs Williams and Greitzer (Ref.3). In this work, stall and surge are seen as limit cycles whose final strength is set by non-linear effects. In origin, these disturbances start out as small perturbations and if treated early enough can be modelled by linear theory. Active control, as envisaged by Epstein et al, would be applied at this linear stage and would employ the feedback of additional disturbances into the flow field to damp out the initial perturbations.

Active control is thus a method of limiting the growth of incipient disturbances and can therefore be thought of as prevention control. The friendly disturbances required to achieve control are generated by a system of actuators driven by a controller using real time information from conditions inside the compressor. Because the damping action is applied when the stall or surge inception disturbances are still very small, the amount of power required to achieve control will also be small. A schematic diagram illustrating the principles of active control is shown in Fig.1.

It is very important to understand the fundamental difference between prevention control, and avoidance control. Both systems are designed to extend the operating range of the compressor, but the technique and the results are different. Avoidance control is achieved by unloading the compressor thus achieving operation at reduced flow rate, but also at reduced pressure rise. This approach is schematically illustrated in Fig.1. for variable stator vane control, and in Fig.2. for fast bleed control. Active, or preventive, control on the other hand aims to damp out the disturbances which cause stall thereby allowing the compressor to operate normally, without an abrupt change in pressure rise, at a flow rate less than is usually possible. (See also Fig.2).

A cautionary note is necessary about the pressure rise achieved when operating in an actively controlled state. Early diagrams illustrating the idea of active control usually showed steep rises in delivery pressure for operation beyond the usual stall limit. This has turned out to be an over optimistic view because active control is not a miraculous way of extracting more work from an already overloaded blade row. Most compressors stall when the slope of the pressure rise characteristic is zero and therefore operation beyond this point is not likely to produce additional pressure rise. This is born out by the experimental results which will be presented below.

2) Active Control of Surge in Centrifugal Compressors

It will be recalled that the performance characteristics of centrifugal and axial compressors are quite different (Fig.4). Centrifugal